PROCESSING AORTIC & PULMONARY ARTERY WAVEFORMS TO DERIVE THE VENTRICLE TIME-VARYING ELASTANCE

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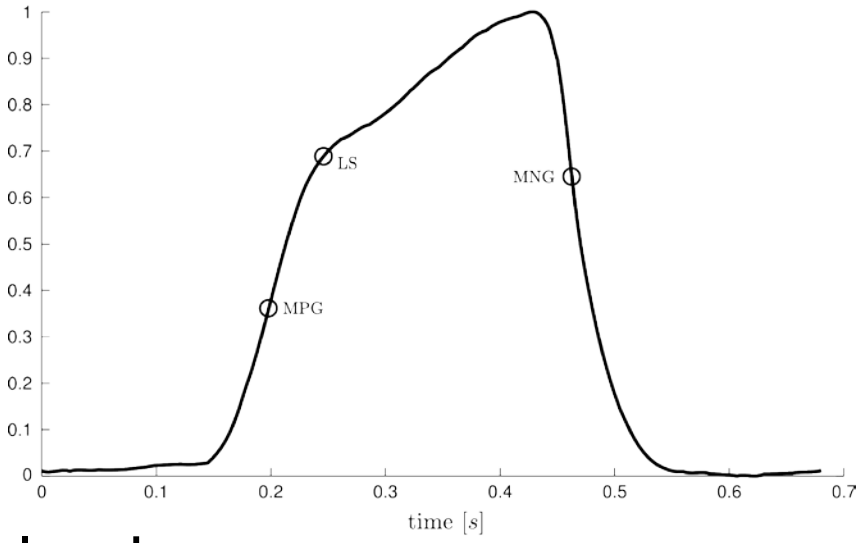
Introduction

- Pulmonary Embolism (and other dysfunction) is difficult to diagnose
  - Difficult to differentiate from cardiogenic shock
- No real time tracking
- A new method for PE diagnosis, but generalisable
  - Uses only arterial pressure, stroke volume and heart rate

Driver function

- Integral part of the CVS
  - But cannot be measured directly in a clinical setting



- Clinically useful on it own
  - Balance of preload & afterload
  - Function of the ventricle energetics
  - Can show a lot of dysfunction directly

The driver function problem

- It can't be measured
  - Requires ventricle pressure and volume
- Estimate it from what can be measured
  - Aortic pressure
  - Timing from the pulmonary artery
  - Global end-diastolic volume (GEDV)

$$el(t) = \frac{P_{lv}(t)}{V_{lv}(t) - V_d}$$

where

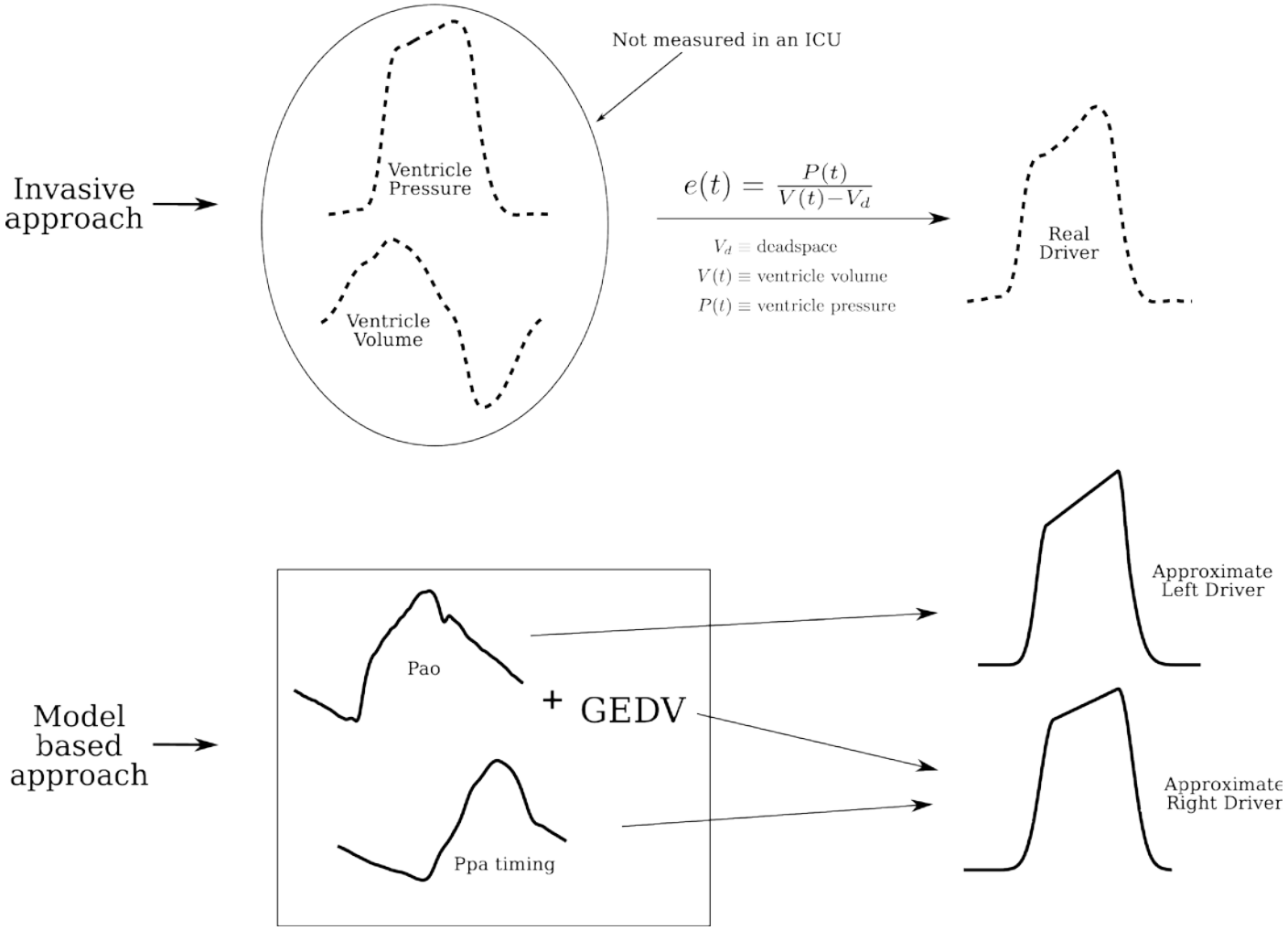
$$V_d \equiv \text{deadspace}$$
$$P_{lv}(t) \equiv \text{left ventricle pressure}$$
$$V_{lv}(t) \equiv \text{left ventricle volume}$$

Trial Data

- Porcine trial
- 5 pigs induced with pulmonary embolism
- 5 pigs induced with septic shock
- Both invasive and non-invasive metrics

Measurement	ICU	Animal trials
Ventricle Pressure and Volume	✗	✓
Aortic Pressure	✓	✓
Pulmonary Artery Pressure	✓	✓
ECG & CVP	✓	✗

Methods – driver function



The Approach

- Find correlations empirically
  - relationships between the “outside” and the driver functions
  - relationships between the left and right driver functions

Relationships used		
Aortic pressure	⇔	Left driver function
Aortic pressure	⇔	Right driver function
Pulmonary artery pressure	⇔	Right driver function
GEDV	⇔	Right driver function
Left driver function	⇔	Right driver function

Correlation metrics
Time
Value
Gradient

- Use population correlations to estimate the driver functions
  - Fit points to exponential curves

The Concept

Invasive to measure

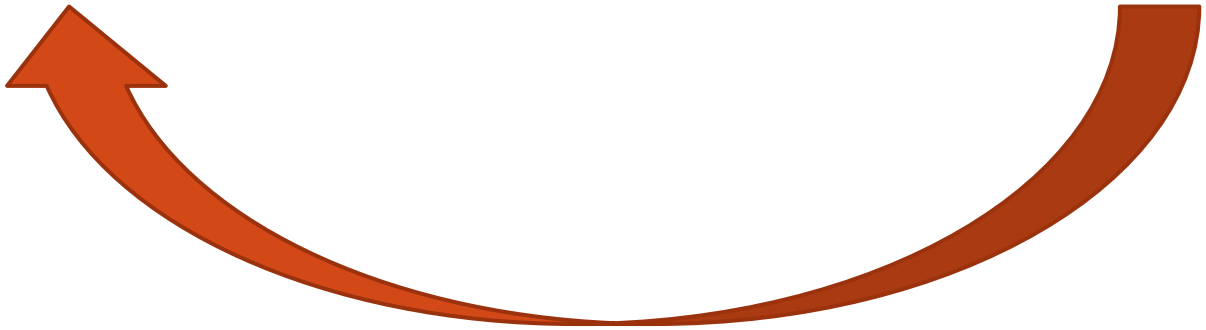
$$\begin{matrix} e_{rv\_true} \\ e_{lv\_true} \end{matrix} + \begin{matrix} P_{ao} \\ P_{pa} \\ GEDV \end{matrix} \Rightarrow$$

Intensive Care Unit

$$\text{Correlations} + \begin{matrix} P_{ao} \\ P_{pa} \\ GEDV \end{matrix} \Rightarrow \begin{matrix} e_{rv\_approx} \\ e_{lv\_approx} \end{matrix}$$

$e_{xv} \equiv$ time-varying elastance for the 'x' ventricle

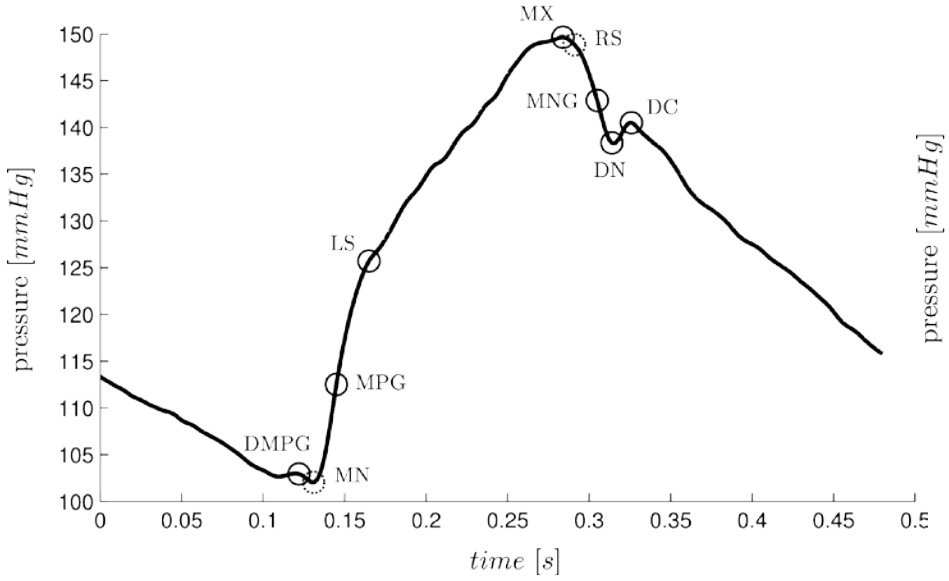
$GEDV \equiv$ global end-diastolic volume



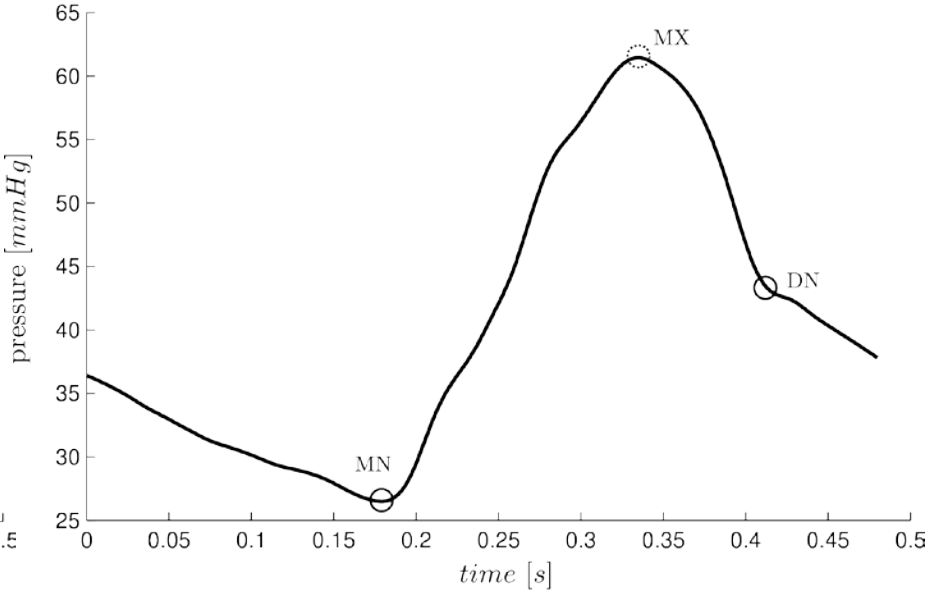
The Processing

- **All this assumes we can find the required points on the aortic pressure waveform**
- Some points are non-trivial to find
- Driver construction is only as good as the aortic processing accuracy and reliability

The Waveforms



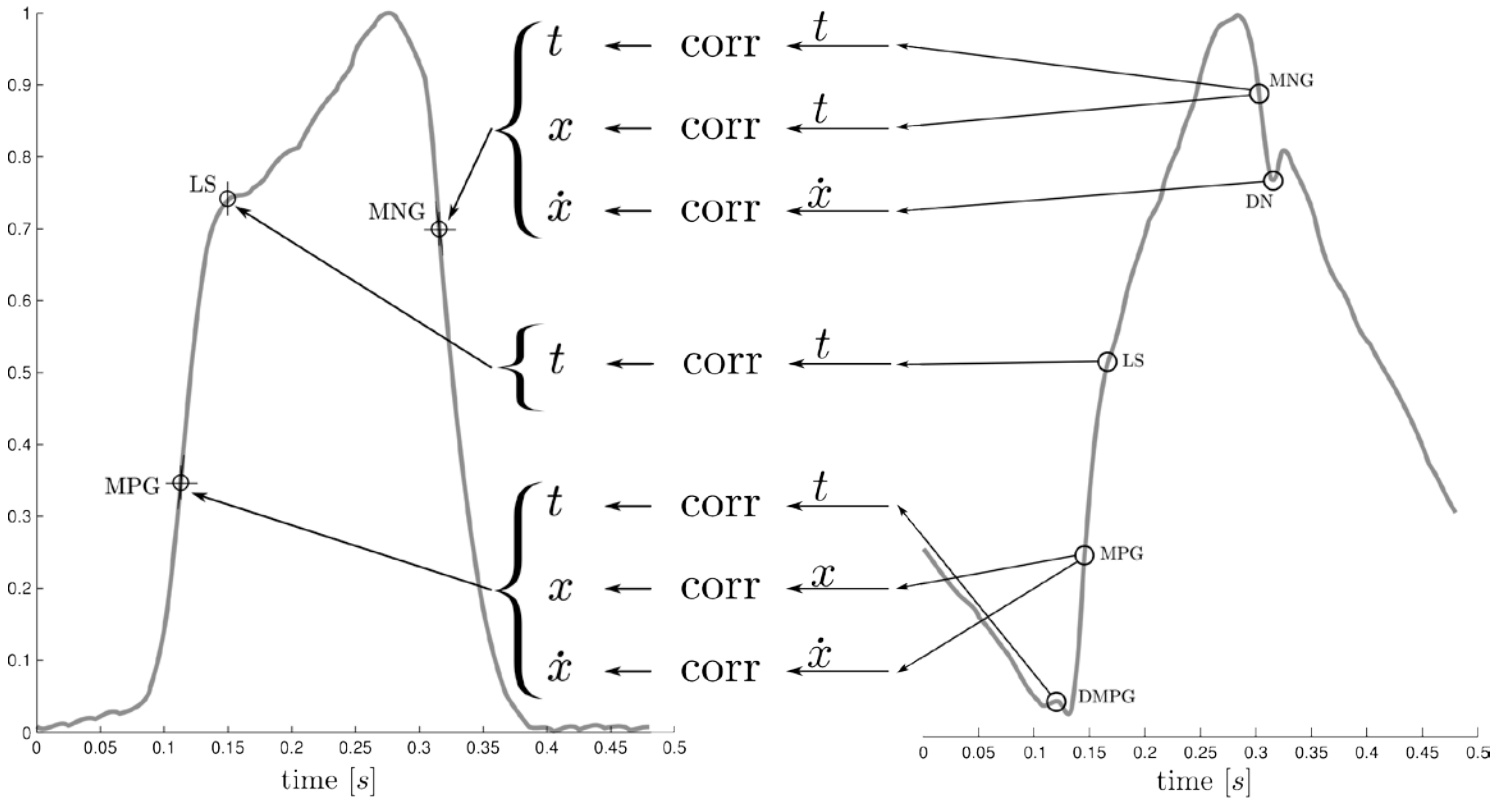
Aortic pressure
Left Side



Pulmonary artery pressure
Right Side

The points

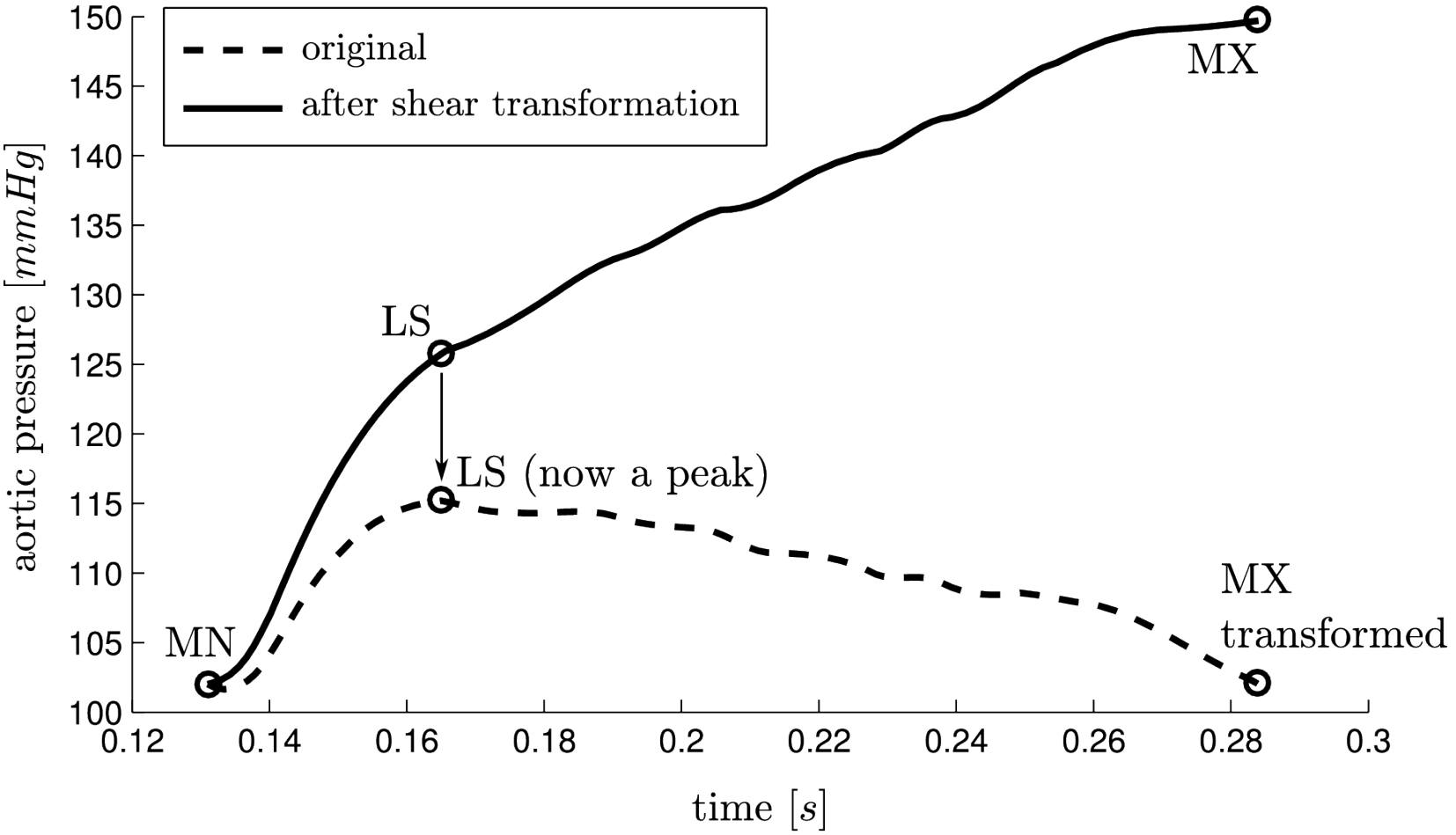
- Each point is correlated in some fashion to a point on the driver function



The Shear Transform

- A novel method for locating features of a waveform
- Enables accurate and reliably processing
- The majority of points use it
- Converts a change of slope into a easy to locate maximum or minimum
- Error checking
  - provides a convenient way to test and confirm the location of a point

The Shear Transform (example)



Locating the points

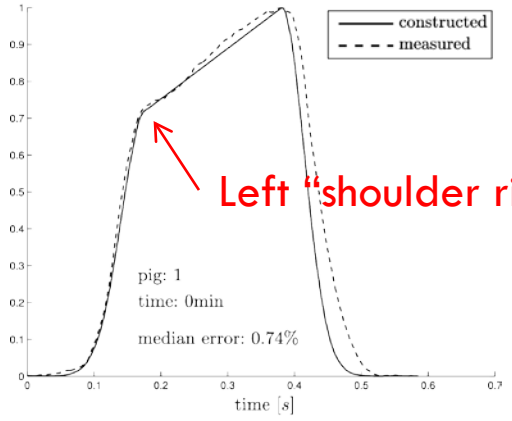
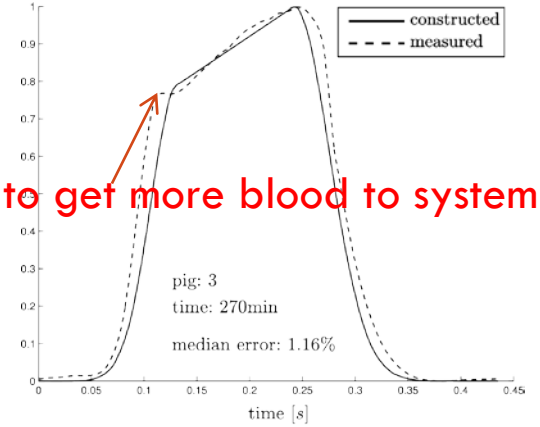
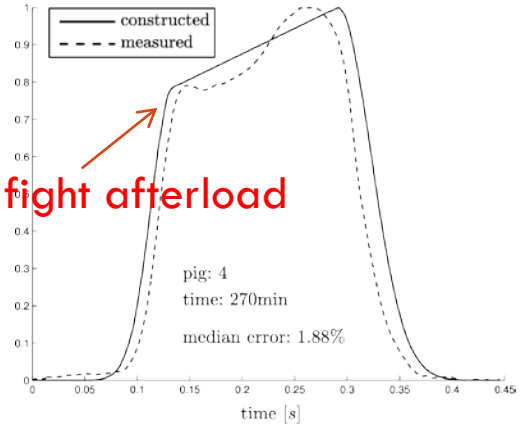
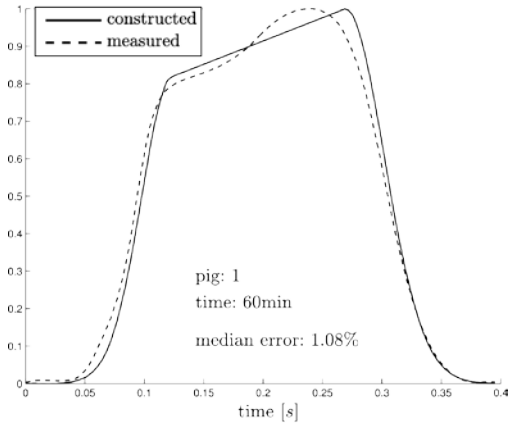
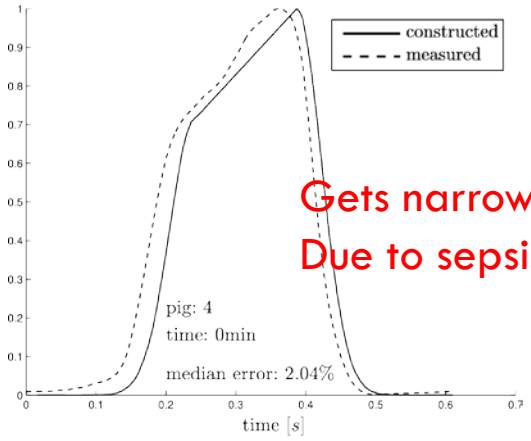
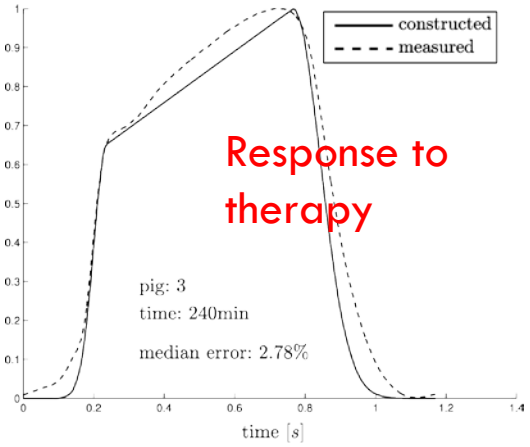
- Refer to the paper for details
- Heavy use of the shear transformation
- Some empirically derived constants

Results - processing

- Very good accuracy
- Cohort included a few very odd waveforms – a few points which could not be located

	< 1%	1 - 5 %	5 – 10 %	10 – 20 %
DMPG	84	1	3	0
MPG	88	0	0	0
LS	86	1	1	0
MX	88	0	0	0
MNG	87	0	0	1
DN	86	2	0	0
DC	86	1	0	1
TOTAL	**605**	**5**	**4**	**2**

Results – driver functions

	5th Percentile case	50th Percentile case	95th Percentile case
Pulmonary Embolism			
Septic Shock			

Left "shoulder rises to get more blood to system and fight afterload

Gets narrower
Due to sepsis

Response to therapy

Results – driver functions

- Extremely good estimations
- Left side slightly better than right
  - Pulmonary Embolism

	Left	Right
Median error	1.14%	2.10%
90th percentile	3.36%	6.57%

  - Septic Shock

	Left	Right
Median error	2.02%	2.85%
90th percentile	5.52%	8.58%

Summary

- Driver functions are invasive to measure directly but have clinical value
- A previously developed method can estimate (very closely) the left and right ventricle driver functions
- The driver estimation requires reliable and accurate location of specific points in the aortic pressure waveform
- A method has been developed along with a novel shear transformation to process the waveforms

Conclusions

- There is a significant amount of information in the driver function
- These driver functions can be estimated through non-invasive means
- Both the estimation and the processing are accurate and reliable

Ongoing …

- Validation in further trials
- Expand to other dysfunction
  - Contractile failure
- Response to therapy

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James Revie


Stefan Heldmann


Aaron LeCompte


Christina Starfinger


David Stevenson


Ashwath Sundaresan


Claire Froissart

Gael Couchy (French Student)

Don’t Forget …

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Questions?

Results – Safe to assume GEDV, t are good?

- Very good correlations for the timing
- Correlations reflect coupling between left and right ventricles
- Correlations for the left side are better